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RELIABILITY MONITORING FOR DEVELOPMENT PROJECTS.(U)

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TECHNICAL INFORMATION SERIES

Title Page

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AUTHOR	SUBJECT CLASSIFICATION	NO. / DATE
J. T. Duane	Reliability	DF62MD300 / 1 Feb 1962

TITLE

Reliability Monitoring for Development Projects

ABSTRACT - Theoretical approach is developed for management control of progress towards pre-determined reliability goals during product development programs. Standards for monitoring are derived from empirically determined characteristic rates of growth for reliability on air-borne accessory types of products. The proposed monitoring techniques assume reliability goals specified in terms of a maximum allowable failure rate after some fixed number of testing or operational hours have been accumulated.

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CONCLUSIONS

1. It is shown that failure rates on relatively complex aircraft accessories follow a relatively simple and predictable pattern and are approximately inversely proportional to the square root of cumulative operating time.

2. Use of the above relationship permits the establishment of a relatively simple technique for monitoring progress towards the attainment of pre-determined reliability goals.

3. Accumulation of additional data and further analysis will be required in order to permit the establishment of confidence levels for the monitoring measurements described.

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For list of contents—drawings, photos, etc. and for distribution see next page (DC-241-A)

INFORMATION PREPARED FOR Aircraft Generator Product Engineering

TESTS MADE BY None

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Introduction

Much development engineering work must be directed and guided in terms of specific reliability objectives to be attained by the equipment or product being developed. Effective accomplishment of such work creates a need for measurement tools which will permit continual monitoring of progress towards pre-determined reliability objectives. Similar requirements for monitoring of progress exist in programs established for the purpose of improving reliability of products or system already in operational service. It is the intent of this report to document a proposed technique for such measurement and monitoring.

In the early stages of product development or during the first stages of a reliability program, it is difficult to determine an accurate measure of performance from a reliability standpoint because the amount of actual experimental data available is usually extremely meager. In order to overcome these problems, a technique is desired which utilizes the largest possible percentage of available data, but at the same time, averages short term fluctuations. For this reason, it is desirable to establish a meaningful index for monitoring which can use data obtained prior to reliability improvements currently in effect. This proves difficult since reliability measurements prior to improvements show lower levels than those which would be considered representative of the latest performance. The method proposed here is intended to permit utilization of such early data with provisions for weighting it in such a way that it contributes to a varied measure of current status and, in addition, provides a graphical representation of the manner in which equipment reliability is changing with time.

The general approach followed in seeking monitoring methods was to analyze previous experience on representative equipments in a search for significant patterns which might provide a basis for development of effective monitoring. This type of review did produce what appeared to be significant patterns and, on this basis, a proposed monitoring procedure was established.

Analysis

In an effort to determine the manner in which reliability performance changes during development and design improvement activity, data was analyzed for a total of five (5) different products. Available reliability data was checked in several different cases in search of consistent patterns which might be assumed to exist for a wide range of equipment types. It soon became apparent that all of the products considered showed a remarkably consistent pattern when cumulative failure rate (defined as total malfunctions since program start, divided by total operating hours since start) was plotted on log-log paper as a function of cumulative operating hours. The data used is shown in Figure 1 in this type of presentation.

It can be seen in Figure 1 that cumulative failure rate data falls very close to a straight line plot and the cumulative failure rate appears to decrease as about the -0.4 or -0.5 power of cumulative operating hours. Variations among the various

curves plotted on Figure 1 are, of course, associated with equipment complexity, design life and individual reliability standards. The curves on Figure 1 represent a broad range of aircraft type equipment. Specific items are not identified here in order to eliminate necessity of restricting the report distribution. However, they can be generally characterized as follows: Curves 1 and 2 represent data on relatively complex hydro-mechanical devices, completely different in function from each other. Curves 3 and 4 show data on relatively complex types of aircraft generators. Curve 3 is interesting in that data was accumulated and plotted from a start point which was taken well after the equipment was initially placed in operational service. Curve 4 shows data accumulated during the very early stages of an in-house test program on a new and radically different type of generator. Curve 5 represents data on a complete aircraft jet engine during the early stages of its introduction into service.

It can be seen that all of these curves form reasonably good straight lines and that they are surprisingly similar in slope. In general, it appears that cumulative failure rate will vary in a manner inversely proportional to the square root of cumulative operating hours. This can be expressed mathematically as:

$$\lambda_\Sigma = K(\Sigma H)^{-\alpha} \tag{1}$$

where $\lambda_\Sigma = \frac{\Sigma F}{\Sigma H}$

ΣF = Cumulative Failures
ΣH = Cumulative Operating Hours
K = Constant
α = Exponent determined by slope

In general, the constant K will depend on equipment complexity, design margin and design objective for reliability. Its actual value will, of course, be an extremely significant index of equipment reliability or failure rate.

Equation 1 implies that reliability will continually increase as operating experience is gained. This may not be true as operating time reaches extremely high values, but the evidence presented in Figure 1 does indicate that the relationship is valid over a long period of operating experience. It is the author's opinion that this relationship probably applies as long as active programs are in place to improve equipment reliability. This was the situation during the periods in which the data shown in Figure 1 was accumulated.

Equation 1 is expressed in terms of cumulative failure rate but reliability objectives are normally expressed in terms of the actual or current failure rate as determined during some limited operating period. It is possible to determine current failure rate in terms of the parameters of Equation 1 when it is recognized that:

$$\lambda_\Sigma = \frac{\Delta(\Sigma F)}{\Delta(\Sigma H)} \doteq \frac{d(\Sigma F)}{d(\Sigma H)} \tag{2}$$

Combining equations 2 and 3 provides the desired expression for the current failure rate (λ):

$$\lambda_\Sigma = \frac{\Sigma F}{\Sigma H} = K(\Sigma H)^{-\alpha} \quad (3)$$

$$\Sigma F = K(\Sigma H)^{1-\alpha} \quad (4)$$

$$\lambda = \frac{d(\Sigma F)}{d(\Sigma H)} = (1-\alpha)K(\Sigma H)^{-\alpha} \quad (5)$$

From Equation 5 it can be seen that the current failure rate is equal to the fraction ($1 - \alpha$) of the cumulative failure rate. From Figure 1 it can be seen that α is approximately equal to 1/2 for most of the equipment shown and, in this case, Equation 1 and 5 reduces to:

$$\lambda_\Sigma = K(\Sigma H)^{-1/2}$$
$$\lambda = \tfrac{1}{2}K(\Sigma H)^{-1/2} \quad (6)$$

Monitoring Procedure

On the basis of the above analysis, it seems reasonable to assume that progress in reliability improvement for equipment under development can be realistically measured in terms of cumulative operating experience. Using cumulative figures provides a realistic basis for establishing relative weighting of recent and older performance data. It offers the added advantage of utilizing all available data and thus, averaging out radical fluctuations which might occur when current operating period data is too limited to provide significant results.

In establishing the proposed procedure it is assumed that Equations 6 apply. It is further assumed that the development or product improvement program has a specific reliability objective expressed in terms of a maximum allowable current failure rate which is to be achieved by the time some fixed number of cumulative operating hours has been achieved. With the objective expressed in these terms, monitoring is accomplished by the use of a form as shown in Figure 2. A solid line is drawn with a slope of 1/2 decade per decade intercepting the vertical line corresponding to the objective value of cumulative operating hours at a point corresponding to a normalized failure rate of 2.0. A sample objective curve is drawn on Figure 2 for a hypothetical product for which the reliability objective is to be achieved by the time 2,500 operating hours have been accumulated. The proposed system then uses the following steps:

1. Establish reliability objectives and prepare a chart similar to Figure 2.

2. On some uniform time basis, plot cumulative failure rate (normalized by dividing by objective) vs. operating time accumulated as of that date. In order to provide additional information on current performance, it appears desirable to also plot the actual or current failure rate experienced for each reporting period, again as a function of cumulative operating hours.

3. Monitoring of progress can be accomplished by observing whether or not plotted data for cumulative failure rate is falling on or below the predetermined "Objective" line. Data falling above the curve indicates a need for specific corrective action over and above normal corrective measures.

The monitoring techniques proposed in this report have not been implemented or evaluated under operating conditions. They are proposed here to document the empirical basis and provide a guide for the use of the principles in an operating trial.

Discussion

The monitoring system proposed here assumes that a "normal" rate of reliability improvement exists. Such a normal growth rate can be useful as a standard against which to compare actual performance but it must not be viewed as an absolute limit (or guarantee) on the performance of any given product. Some products will do better and some not as well. It is obviously possible to effect step changes in the current failure rate performance of some products with specific design changes. The procedure proposed here should not be interpreted as denying this, but only requiring that improvement be reflected in the cumulative failure pattern as evidence of reliability growth.

Since the proposed procedure is intended primarily for use in connection with development projects, it is important to note that test conditions have a major effect on the data validity. Early test data will never be entirely representative of operational conditions, but the closer it simulates such conditions, the better will be the accuracy of extrapolation from test stand curves to operational data.

Extrapolation of failure rate data by straight line extension of experimental curves on Figure 2 provides an obvious way of predicting reliability at given points in the development cycle. It appears that such predictions should be valid although relatively conservative (if the cumulative rate curve is used). It would be extremely helpful if specific confidence levels (or limits) could be associated with these predictio At the present time, there does not seem to be enough experimental data available to support the establishing of such confidence levels. Accumulation of such data and associated analysis may be a particularly fruitful area for further effort on the development of methods for monitoring reliability growth.

Conclusions

1. It is shown that failure rates on relatively complex aircraft accessories follow a relatively simple and predictable pattern and are approximately inversely proportional to the square root of cumulative operating time.

2. Use of the above relationship permits the establishment of a relatively simple technique for monitoring progress towards the attainment of pre-determined reliability goals.

3. Accumulation of additional data and further analysis will be required in order to permit the establishement of confidence levels for the monitoring measurements described.

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FIG #1

CUMMULATIVE FAILURE RATE TRENDS

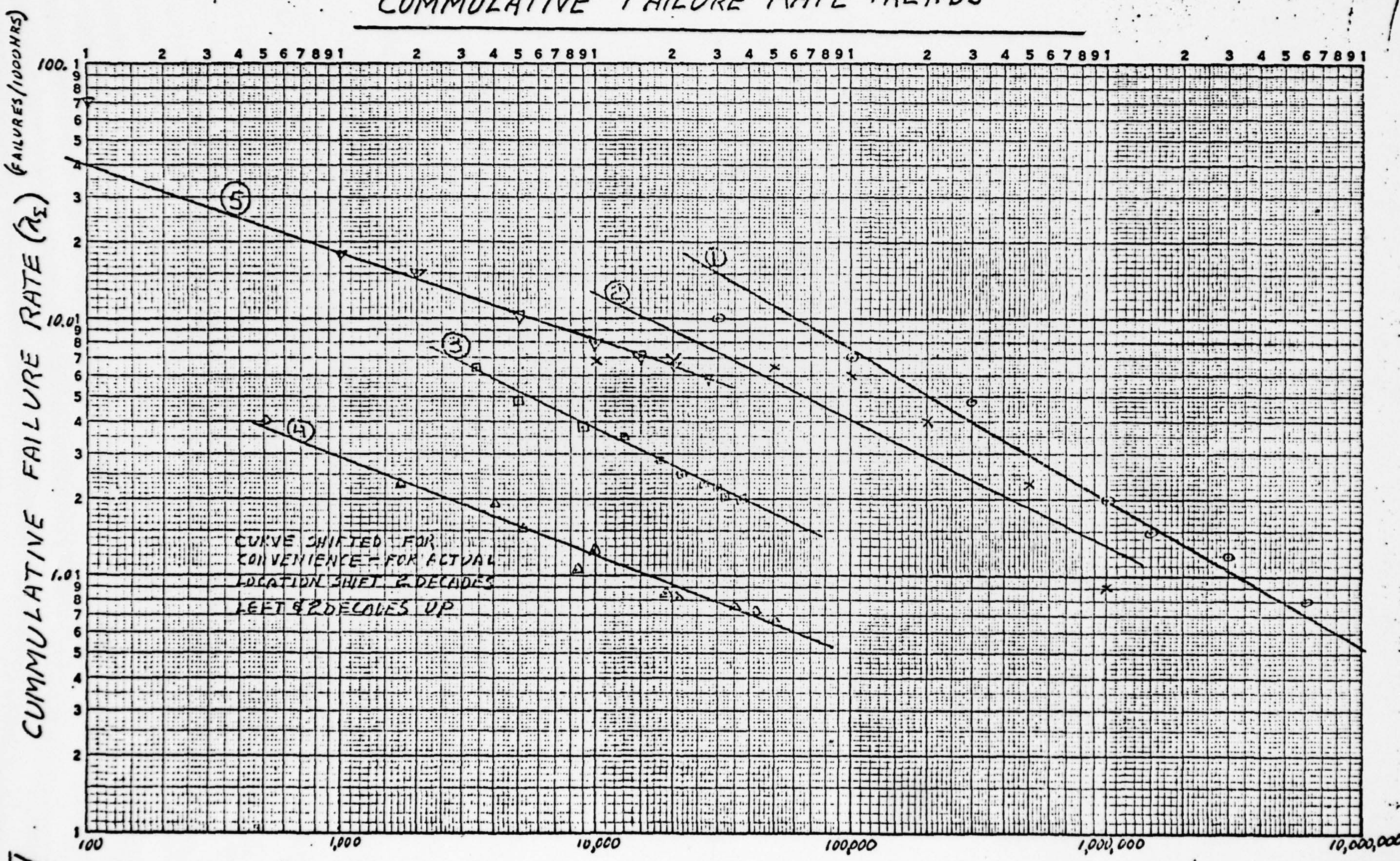

FIG #1

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RELIABILITY OBJECTIVE

MODEL NO. 2CMXXXA1

FAILURE RATE .08/1000 HRS

BY 2500 CUMM. HRS.

FIG #2

RELIABILITY PROGRESS CHART

(For usage see PR. 537.1-7)

EXAMPLE

MONTHLY REPORT

ISSUED BY	CUMM. HRS.	DATE
JTD	50	2-1-6?
JTD	150	3-1-6?
JTD	350	4-1-6
JTD	1000	5-1-6
JTD	2500	6-1-6

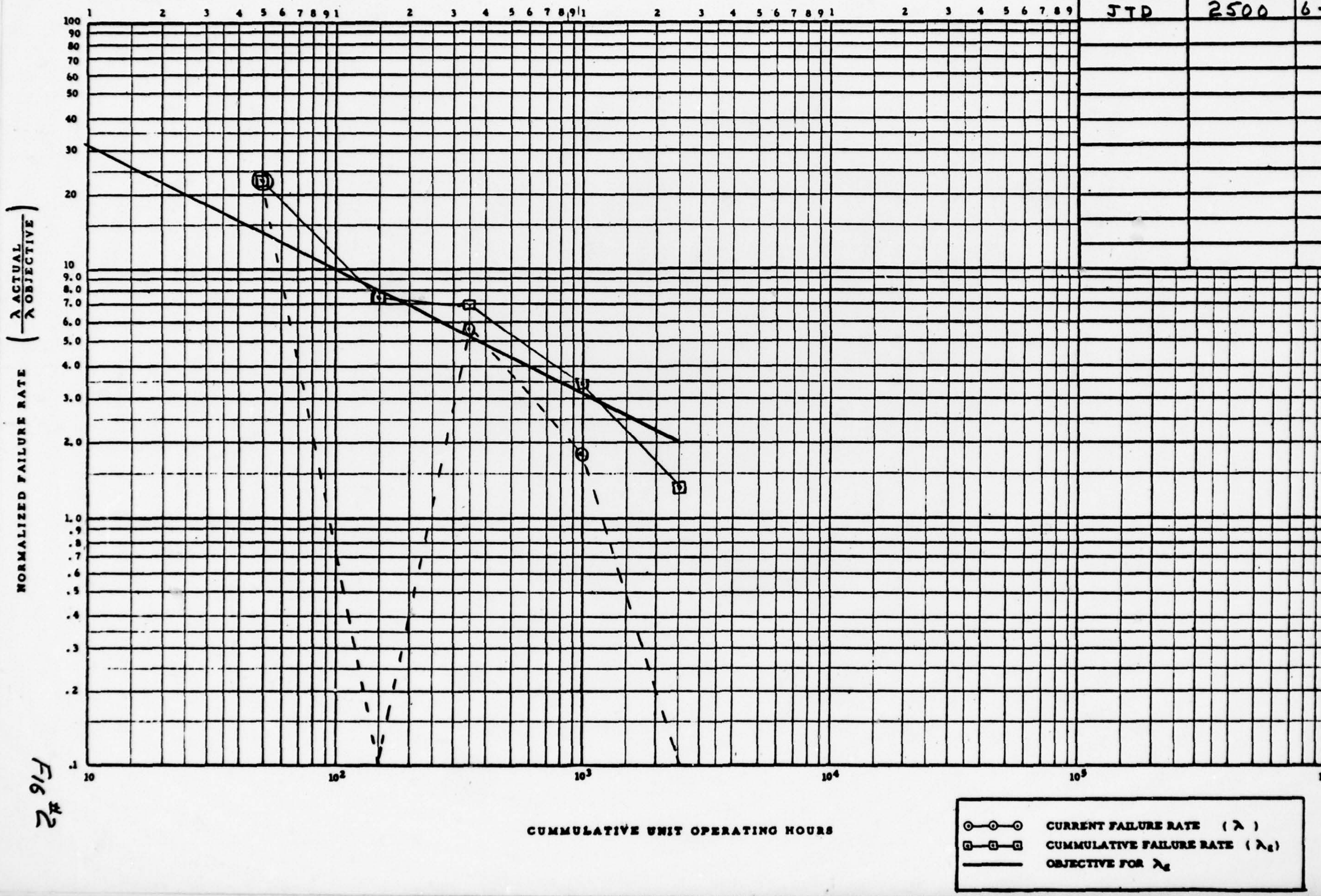

FIG #2